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LANDSCAPE AND ENVIRONMENTAL CHANGE IN GLACIER NATIONAL PARK, MONTANA, U.S.A.

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INTRODUCTION

Glacier National Park (GNP), Montana is sensitive to climate change as observed through glacial retreat (e.g., Key et al., 2002) and ecosystem adjustments (e.g., Klasner and Fagre, 2002), and there is widespread interest in the effects of future climate change in this unique and public space. Our research project was aimed at understanding environmental and climate change variability in near-pristine alpine basins in North America, with the goal of collecting data that is relevant to the debate about landscape response to climate change in the northern Rockies since the last glaciation. The research project has relevance to the research communities in geomorphology, Quaternary geology, glaciology, and paleoclimatology, as well as to the general public interested in climate change since the retreat of Ice Age glaciers.

The choice of lakes on which to focus during the project was based on a substantial body of past work in the Many Glacier Region of eastern GNP. In 2005, 2010, and 2014, we collected lake cores in Swiftcurrent Lake, Lake Josephine, and lower Grinnell Lake, all of which are located downstream of Grinnell Glacier (Figures 1 & 2). Work done on these cores by previous students (many of them as part of Keck projects) has provided additional constraints on climate and environmental history in the basin since the end of the Last Glacial Maximum (e.g., MacGregor et al., 2011; Schachtman et al., 2015). The overarching goal of the project this year was to understand sediment transport and deposition in the lower end of Swiftcurrent and Grinnell valleys, and how those processes document

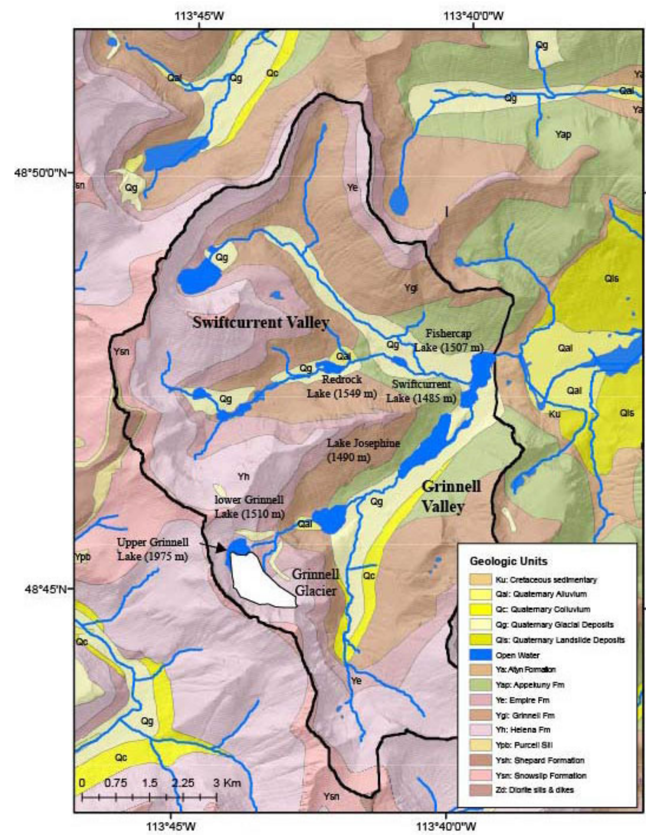

Figure 1. Geologic setting of the Many Glacier area of Glacier National Park, MT. Geologic units are generally either Precambrian meta-sedimentary formations or Quaternary surficial deposits. The southern valley (Grinnell Glacier Valley) has Grinnell Glacier in its headwaters, and serves as the source of water, sediment, and water-borne debris for most of the lake cores. The northern valley (Swiftcurrent Valley) contributes water to the northern subbasin of Swiftcurrent Lake. Map after MacGregor et al., 2011, from Whipple, 1992; courtesy of C. Riihimaki, Princeton University.

changes in environment and climate over centuries to millennia. Our field work included the collection of lake sediment cores from two lakes (Fishercap and Swiftcurrent), measuring water discharge and sediment concentrations in lakes and streams to

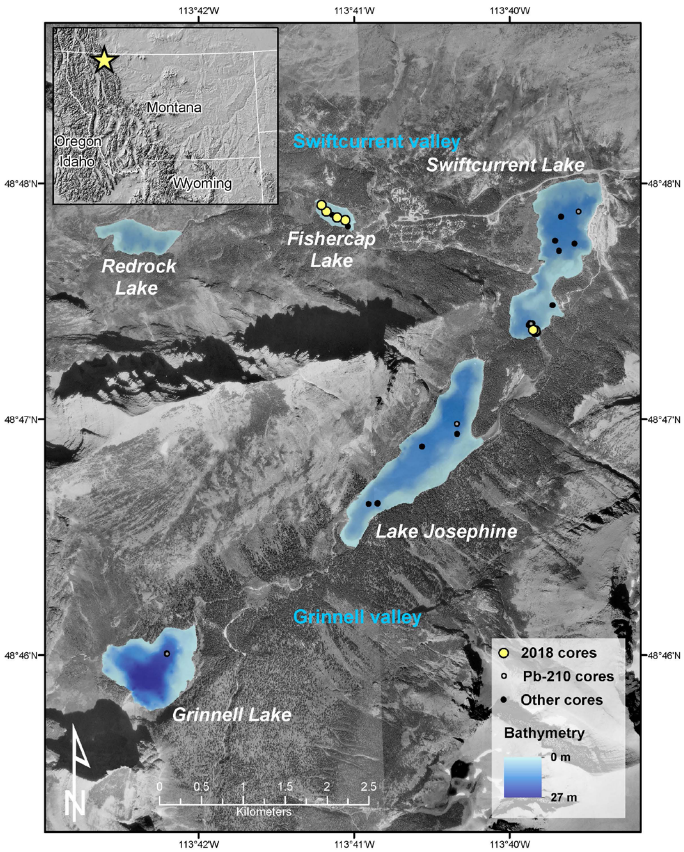

Figure 2. Map of Swiftcurrent and Grinnell Valleys, Glacier National Park, MT. Coring sites from 2018 shown as yellow dots, with coring sites from previous years as black dots. Blue shading represents lake bathymetry collected between 2010-2018.

investigate the sediment budget in the valley systems, measurements of lake bathymetry (depth) for lakebed morphology and sediment trapping efficiency, and reconnaissance of two lakes (one in Swiftcurrent valley, another on the Park's West Side) for future coring.

In summer 2018, eight students (including one near-peer mentor) participated in the Glacier National Park Gateway Keck Geology Consortium project (Figure 3). Students arrived in Minnesota and spent five days at Macalester College for classroom and laboratory 'crash courses' to prepare for the project. This included mini-lectures, hands-on activities, training at LacCore, grocery shopping, meal planning, and gear organization. Most students had taken no more than one geology course, so we spent some of the early meetings talking about major earth science concepts and the nature of scientific inquiry in geology. This included the geologic evolution of GNP (sedimentary rock formation, igneous intrusions, mountain-building), global climate change (Pleistocene, Holocene, and recent), and surface processes (weathering and hillslopes, glacial erosion, fluvial transport). After packing the vans to the brim, we spent two days driving to Many Glacier (camping in Makoshika State Park, MT on the way out). Upon arrival to Many Glacier, we learned the National Park Service (NPS) campground was closed to tent camping due to grizzly bear activity and were relocated for two nights to the Rising Sun campground in St. Mary's, about an hour drive south. The campground was beautiful and we enjoyed getting to know Sue (the camp host), but were happy to move closer to our field area when the bear threat was reduced. We spent 10 more amazing days camping, cooking, and working in the Many Glacier campground.

Figure 3. Field photo of the group on a sunny day hiking on the Continental Divide, Glacier National Park, MT.

The first several days in the field were spent getting to know the geology, biology, and history of the Park, talking with Park Rangers/Interpreters, getting our boats inspected for invasive species control, and carrying all of our equipment to the first lake we cored (Fishercap). Most days we divided into two teams, with Team A on the coring craft and Team B collecting bathymetric data, water and sediment discharge samples, and talking with curious Park visitors who were hiking past where we were working. Students rotated regularly among these groups to learn and practice different methodologies. We collected a total of 2.6 meters of core from Fishercap Lake and 14.2 meters of core from Swiftcurrent Lake. We did several group hikes, including a Ranger-led hike to Iceberg Lake, a group hike to Grinnell Glacier, and a hike up to Logan Pass along the continental divide (mountain goats and marmots included!). We also drove to West Glacier and hiked through part of the area burned during the 2017 fires near Lake McDonald Lodge;

Figure 4. Photo of group with Many Glacier Park Rangers after research presentation (Bear Ranger Bob featured).

this included a reconnaissance trip to Fish Lake for future coring. Our daily conversations with the public (on the trail, from sampling sites, in the campground, at the evening Ranger talks) were highlights, as was the talk we gave to the Many Glacier NPS staff about our research (Figure 4). The constant public contact helped the students to develop their "elevator pitches" for talking about their research, which served them well when they presented their posters at GSA.

After returning to the Twin Cities, students spent two weeks analyzing the cores and other data we collected in the field. Measurements of the sediments' geophysical properties (density, magnetic susceptibility) were collected on the whole core (0.5 cm resolution) using the Geotek Multi-Sensor Core Logger. Cores then were split lengthwise, cleaned, and imaged at 20 pixels per mm on the Geotek CIS linescan digital camera. Initial core description (ICD) was done following the nomenclature found in Schnurrenberger and others (2003). Smear slides were taken in horizons of interest to look at the clastic, authigenic, and biogenic components of the sediment. Split core sections were then logged on the Geotek XYZ at 0.5 cm resolution for high-resolution magnetic susceptibility and color reflectance. Students ran loss-on-ignition (LOI) on every centimeter of the cores, made and described smear slides, helped with correlation of overlapping cores, dried and weighed filters, and made calculations of water discharge and suspended sediment concentrations. Finally, students divided into two groups and wrote and submitted abstracts for GSA (MacGregor et al., 2019; Myrbo et al., 2019).

The entire group reconvened in Indianapolis, Indiana for GSA in November 2018 to present the results of their research in a Limnogeology poster session (Figure 5). The two posters, "Sediment transport and deposition in Fishercap Lake and the Swiftcurrent Valley, Glacier National Park, Montana, USA" and "Using lake cores to analyze sediment transport and environmental change in Swiftcurrent Lake, Glacier National Park, Montana, USA" were busy with visitors; both can be found on the Keck Geology website. Below is a summary of the research motivation and findings of the GNP Gateway students.

Figure 5. Photo of group during presentations at GSA in Indianapolis, IN, 2019.

FIELD SETTING

The Many Glacier region of Glacier National Park, Montana is located to the east of the Continental Divide and includes several small cirque glaciers and glacially carved lakes (Figure 1). Swiftcurrent Lake, the most accessible of the formerly glaciated lakes, receives water and sediment from two valleys: the southern subbasin of the lake has a 36-km2 drainage basin that includes Grinnell Glacier (~2000 m elevation), Upper and lower Grinnell lakes, and Lake Josephine, while the northern portion of the lake has a drainage area of 44 km2 that includes Swiftcurrent Glacier, Iceberg Lake, Bullhead Lake, Redrock Lake, Fishercap Lake, Swiftcurrent Creek and its tributaries. The Many Glacier Hotel, completed by 1918, sits near the Swiftcurrent Lake outlet.

The entire drainage basin is underlain by the Middle Proterozoic Belt Supergroup, which is comprised primarily of siltsones, shales, and sandstones (Figure 1; Horodyski, 1983). Grinnell Glacier is currently eroding the stromatolitic Siyeh Limestone of the Helena Formation, which consists of dolomitic limestone and calcitic argillite (Whipple, 1992). The only bedrock source of dolomite in the valley is at the highest elevations of the basins, and is the rock on which Grinnell and Swiftcurrent glaciers currently reside. Lake Josephine and Swiftcurrent Lake are underlain by late Pleistocene tills on order of 1-3 m thick (Earhart et al., 1989; Carrara, 1990; Whipple, 1992). Recent work by Schachtman and others (2015) shows that Grinnell Glacier was likely at or near the southern end of Swiftcurrent Lake at ~17 ka based on the presence of varved sediments in the lake.

KEY FINDINGS

Swiftcurrent Valley

Our goal was to provide some initial morphometric data on the lakes, and to characterize the transport and deposition of material in transport from Swiftcurrent Valley into the northern basin of Swiftcurrent Lake. We measured bathymetry of Fishercap and Redrock lakes, the two lakes furthest downvalley in a chain of paternoster lakes in the Swiftcurrent Valley, which joins the Grinnell Valley at Swiftcurrent Lake. Our bathymetric measurements and coring demonstrated that Fishercap Lake is relatively shallow (~0.8 m; Figure 2) and uniform in depth, with a slightly deeper upvalley region. Redrock Lake had a maximum water depth of ~6.5 m, with the deepest water on the southern edge of the lake, which may be structurally controlled. We also collected a downlake transect of cores from Fishercap Lake, the final lake in the chain. Fine sediment accumulation in Fishercap Lake is generally massive, with organic content ranging from 5-40% with an average of 15%. The most upvalley core contained laminated sediments in contrast to the other three cores in the transect. We observed frequent moose grazing in the lake, suggesting macro bioturbation of lake sediments. There was a dense gravel layer below the sediment-water interface that appears to be uniform across the basin, potentially suggesting past desiccation of the lake. The fine-grained sediment above the gravel is thickest at the upvalley end of the lake (85 cm) and grades to 40 cm at the downvalley end of the lake.

To constrain the timing of possible lake dessication, we collected basal charcoal radiocarbon samples at the bottom of all four Fishercap Lake cores, and collected an additional sample from the most upvalley core that contained laminations. Ages for cores 1-3 are somewhat difficult to interpret based on their young age (during a period when the radiocarbon calibration curve is complicated), but are within the past ~500 years. The most upvalley laminated core was significantly older with a basal age of ~4400 radiocarbon years. This suggests a portion of the lake may not have fully dried, or that the gravel layer represents an older dessication event with a hiatus in deposition in the majority of the lake basin. Notably, Fishercap is significantly more shallow than any lake in the Grinnell Valley, and is therefore unlikely to be an important sediment trap for material moving down Swiftcurrent Valley (MacGregor et al, 2019).

Grinnell Valley

We collected a transect of three composite cores along the inlet delta region of Swiftcurrent Lake where the stream enters from Lake Josephine. Bathymetric data showed increasing water depths with distance from the inlet stream (Figure 2). Core sediments contained laminations but were not varved, and were generally silt and clay-rich with minor sandy contributions. Diatoms were pervasive in the top several meters of sediments, and clastic units are comprised of several clay minerals, quartz, feldspars, and dolomite. In all three Swiftcurrent Lake cores we collected the Mazama ash (7.7 ka; Zdanowicz et al., 1999), and the longest core contained the Glacier Peak G ash (13.55 ka; Kuehn et al., 2009; Foit et al., 1993; Mehringer et al., 1984) and Mount St. Helens J ash (13.87 ka; see Schachtman et al, 2015 for references). The Mazama ash occurs at different depths in each core in the transect, and shows that sedimentation rates are variable across the inlet despite similar water depths. Hiatuses are also likely in these sequences. We calculated average sedimentation rates from the top of the Mazama tephra (7630 BP) to the present. From proximal to distal from the inlet (sites 1-3, respectively), those rates were 0.19, 0.41, and 0.52 mm/yr. The average sedimentation rate for the Schachtman et al (2015) core, farther from the inlet, is 0.59 mm/year. Sedimentation rates increase with distance from the inlet, which was surprising: we originally hypothesized that more transported sediments would be deposited closer to where the stream enters the lake. This finding, suggests that the inlet stream is eroding as well as depositing sediment, and that some transported sediment may bypass the delta entirely, especially during high water discharge periods. Smear slides show an increase in grain size from clays dominating sediments older than the Glacier Peak G/Mt. St. Helens J ashes to coarser sediment in the upper ~2 m of the cores (Myrbo et al., 2019).

Suspended sediment and water discharge data

We measured suspended sediment concentrations at inlets and outlets of Redrock, Fishercap, and Swiftcurrent lakes to provide preliminary insights into sediment sources and sinks within the valleys. Preliminary total suspended solids (TSS) data show TSS is higher at the outlets than at the inlets of Redrock and Fishercap lakes, suggesting that the lakes are not currently efficient sediment traps and may be sources of material for Swiftcurrent Lake. Comparison of sediment concentrations from Swiftcurrent and Grinnell Valleys suggests that Swiftcurrent Valley transports more sediment than Grinnell Valley into Swiftcurrent Lake. Preliminary estimates of water discharge coming from Lake Josephine show more water enters Swiftcurrent Lake from Grinnell Valley than that from Swiftcurrent Valley, but TSS concentrations are lower in the Grinnell Valley discharge. This has implications for our interpretations of climate and environmental change from cores that receive sediment and water from both valleys (MacGregor et al., 2019; Myrbo et al., 2019).

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